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REPORT

RADIO-FREQUENCY DETONATION HAZARDS: multiple-transmission safety assessment of a detonator loop that may be resonant

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RADIO-FREQUENCY DETONATION HAZARDS: MULTIPLE-TRANSMISSION SAFETY ASSESSMENT OF A DETONATOR LOOP THAT MAY BE RESONANT

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Summary

When a number of electro-explosive devices are connected in series to form a loop, currents induced by radio transmissions can cause premature detonation if they are strong enough. The hazard will be increased if the loop is inadvertently tuned, but a resonance of this type cannot occur at more than one frequency at a time. The report describes a safety assessment procedure which may be used when several transmissions are present simultaneously.

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1. Introduction

Radio transmissions can induce currents in electro-explosive devices (EED) used for quarrying and similar purposes, and there is a risk of premature detonation if the induced currents are sufficiently strong. The problem has been discussed elsewhere[1] and rules for avoiding the hazard are contained in a British Standard Guide[2]. This report considers a particular aspect of the safety assessment which is referred to in Clause 9.5 of the British Standard Guide.

In practice a number of EED are wired up in series in a loop, which is then connected to an exploder through a firing cable. Under some circumstances the capacitance of the firing cable can tune the loop and increase the induced current, leading to a greater hazard. However significant resonance effects can only occur at the lowest fundamental resonance frequency and a loop cannot be tuned to more than one frequency at a time; this should be taken into account when two or more transmissions induce currents in the loop.

In clause 9.5 of the British Standard Guide[2], multiple transmissions are taken into account by, in effect, adding the largest powers which can be dissipated in EED by individual transmissions and, for this purpose, loops with perimeters less than 0.15λ (where λ is the wavelength) are assumed to be tuned provided the firing cable is of a suitable length. However the inclusion of two or more resonant currents in the power sum leads to an over-estimate of the effective current* and might indicate a hazard where none exists.

A similar problem arises when several transmissions are incident upon an industrial plant where there is a risk of ignition of explosive atmospheres. Since a plant structure cannot be tuned to more than one frequency at a time, the relevant British Standard Guide[3] contains a curve which enables the maximum power which can be extracted from a detuned structure by a resistive load to be estimated; the derivation of this curve is described in an earlier BBC Report[4]. The British Standard Guide for explosive atmospheres contains a safety assessment procedure in which the structure is assumed to be tuned to each frequency in turn. For each tuning condition the sum of the extractable powers is calculated with the help of the curve. The power sums for all the tuning conditions are then compared, the largest sum being selected because this represents the worst case.

* Since the total power dissipated in a resistor is proportional to the sum of the squares of the currents, the effective current is the square root of this sum.

The British Standard Guide concerned with EED[2] recommends a similar procedure, which is described in this Report, when a loop containing EED is able to be tuned to more than one of the frequencies involved. The theory resembles that derived for plant structures in the earlier BBC Report[4] but is less complicated.

2. Current induced in a detuned loop

Fig. 1 (overleaf) shows the equivalent circuit of a small loop at a particular transmission frequency f_t. If the loop is short-circuited the induced current I_{sc} is given by

$$I_{sc} = \frac{V}{(R^2 + X^2)^{1/2}} \qquad (1)$$

where V is the induced voltage and R and X are the resistance and reactance of the loop respectively. If the loop is tuned to resonance by means of the capacitor* shown in Fig. 1, the induced current has a maximum value given by

$$I_{max} = V/R \qquad (2)$$

The ratio of these two currents, denoted by Q, is given by

$$Q = \frac{I_{max}}{I_{sc}} = \frac{(R^2 + X^2)^{1/2}}{R} \qquad (3)$$

Measured values of Q can be derived from Table 1 of Reference 1. Values for loops with perimeters less than 0.15 λ lie between 7.1 and 15.1; a value of 10 is typical and will be assumed here.

The loop will resonate at some

* In practice a loop would be tuned by a firing cable which presents a capacitive reactance to the loop. The assumption of a lumped capacitor made here will have very little effect on the behaviour of a loop near resonance.

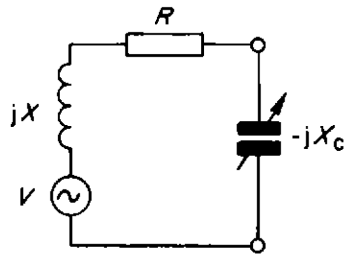

Fig. 1 — A small tuned loop.

frequency f_r and in general will be detuned at the transmission frequency f_t. If the reactance of the tuning capacitor at f_t is $-jX_c$ then at f_r it will be $-jX_c f_t/f_r$. The reactance of the loop at f_r will be jXf_r/f_t. At resonance these two reactances will be equal and opposite. Consequently the value of f_r can be derived from the equation:-

$$X_c \frac{f_t}{f_r} = X \frac{f_r}{f_t} \tag{4}$$

At the transmission frequency f_t the current I induced in the detuned loop is given by:-

$$I = \frac{V}{[R^2 + (X - X_c)^2]^{½}} \tag{5}$$

Substitution of Equations (2), (3) and (4) into Equation (5), followed by re-arrangement, gives the following result:-

$$\frac{I}{I_{max}} = \frac{1}{[1 + (Q^2 - 1)(1 - f_r{}^2/f_t{}^2)]^{½}} \tag{6}$$

Figure 2 shows I/I_{max} as a function of f_t/f_r for Q= 10, calculated from Equation (6). It shows how the current induced by a particular transmission of frequency f_t varies as the loop is tuned through a range of frequencies. When $f_r \ll f_t$ the capacitor is so large that the loop behaves almost as if it is short-circuited. Consequently I/I_{max} tends to $1/Q$ = 0.1 for large values of f_t/f_r. On the other hand, if the loop is resonant at a much higher frequency than f_t, the tuning capacitance becomes so small that the loop behaves almost as if it is open-circuited and the current tends to zero.

It is of interest to compare Fig. 2 with the corresponding curve for plant structures, shown in Fig. 3. It can be seen that:-

(i) the loop curve is much sharper

(ii) the two curves are the opposite way round.

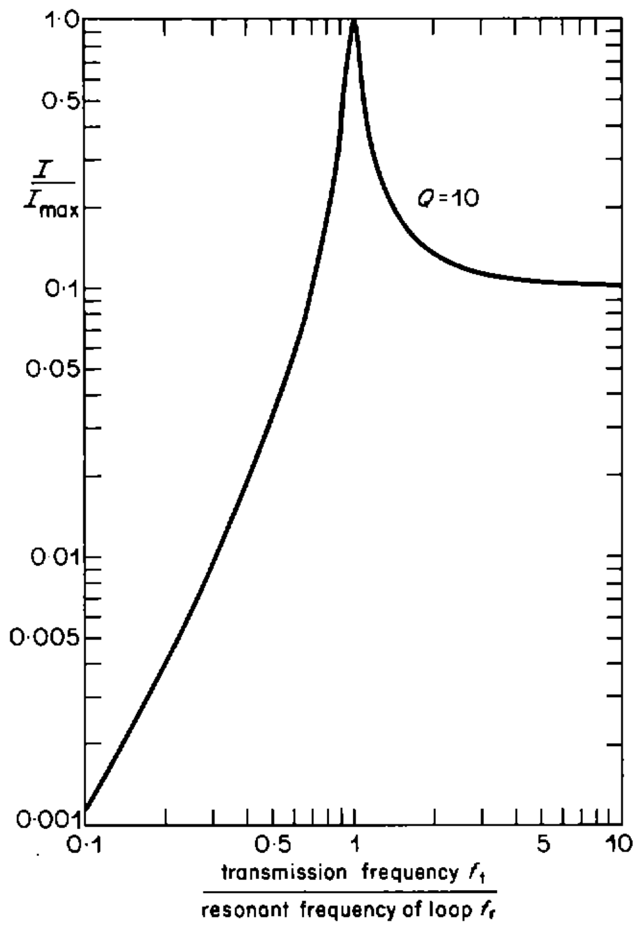

Fig. 2 — Current induced in a detuned loop.

The loop curve is sharper partly because a Q value of 10 (rather than 5) has been assumed, but mainly because the resonance curve for the current induced in a detuned loop is much sharper than that for the maximum power which can be extracted from a detuned structure. The curves are the opposite way round because loops are assumed to be series tuned but structures are assumed to be parallel tuned.

Although the resonance curve is sharp, it is not so sharp that, when the loop is tuned at one transmission frequency, it may be taken as completely detuned at all others. Small loops can be tuned to m.f. broadcast frequencies and some BBC stations radiate m.f. transmissions

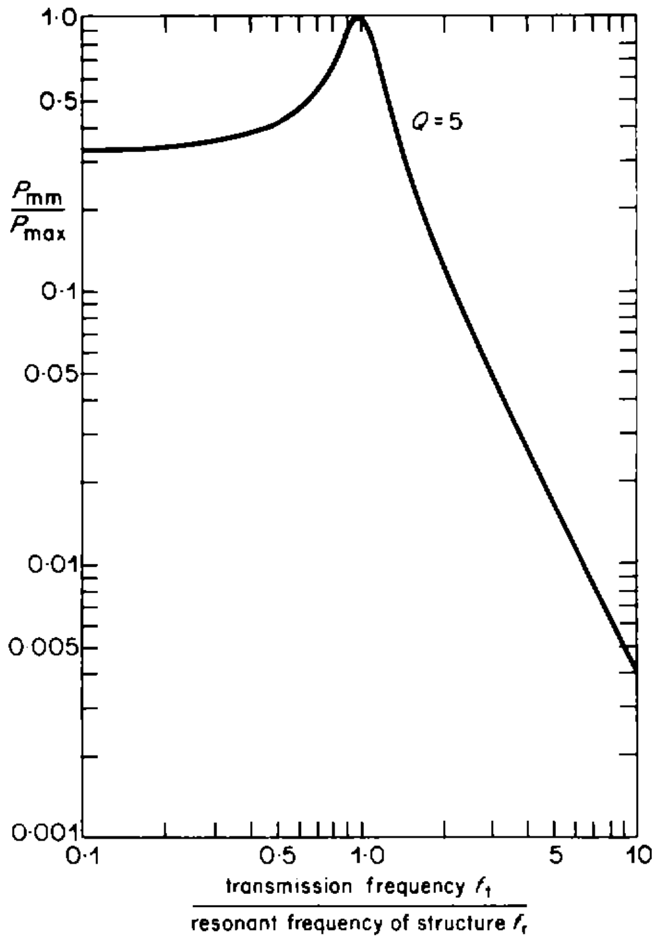

Fig. 3 — Power extractable from a detuned structure.

P_{mm} Maximum power which can be extracted when structure is detuned.

P_{max} Maximum power which can be extracted when structure is tuned.

whose frequencies differ by only 12%. When a loop is detuned to this extent, the induced current is still within 40% of the value at resonance (see Fig. 2).

The application of Fig. 2 to a multiple-frequency assessment is best illustrated by an example. The procedure described in the next section is similar to that described in Reference 3.

3. Example

Consider a 30 m loop and four transmissions in turn, having frequencies of 0.2, 0.9, 1.1 and 1.2 MHz. The loop can be tuned to any of the four frequencies since its perimeter is less than 0.15λ.. The transmissions are assumed to have the field strengths stated in Table 1.

Table 1

Transmission frequency f_t MHz	Field Strength V/m	Current when loop is tuned to f_t I_{max}, mA
0.2	1.0	150
0.9	1.0	150
1.1	0.6	90
1.2	0.8	120

The third column in Table 1 gives the induced current which is assumed when the loop is tuned; it is based on the current of 150 mA for a field strength of 1 V/m, given in Fig. 18 (c) of Reference 1. If in the presence of four transmissions the loop was assumed to be tuned to all four frequencies simultaneously, the effective total current (square-law addition) would be 260 mA.

Table 2 shows the currents which would be induced if the loop were tuned to each frequency in turn. The individual currents are calculated by multiplying the resonant currents given in Table 1 by values of I/I_{max} obtained from Fig. 2, or calculated from Equation (6) with $Q = 10$.

The right-hand column of Table 2 shows that the effective current is greatest when the loop is tuned to 0.9 MHz; this value would therefore be used in the hazard assessment. It is only 60% of the value derived above from the four resonant currents.

Table 2 also shows that, when the loop is tuned to frequencies greater than 0.2 MHz, the currents induced at 0.2 MHz are much smaller than the minimum current of 10 mA shown in 18 (c) of Reference 1, even though the field strength is the same. However there is no inconsistency because the current of 10 mA applies to a closed loop; the insertion of a tuning reactance presents a high impedance to the loop at frequencies below the resonant frequency and reduces the current.

4. Safety assessment for multiple transmissions

In Clause 9.5. of the British Standard Guide[2] a safety ratio ρ, defined as

$$\rho = \left(\frac{E_m}{E_s}\right)^2 \qquad (7)$$

TABLE 2 Currents Induced in Detuned Loops

Frequency to which loop is tuned f_r, MHz	Transmission frequency f_t, MHz	$\frac{f_t}{f_r}$	$\frac{I}{I_{max}}$	I_{max} mA	I mA	Effective current mA
0.2	0.2 0.9 1.1 1.2	1.0 4.5 5.5 6.0	1.0 0.105 0.103 0.102	150 150 90 120	150 16 9 12	152
0.9	0.2 0.9 1.1 1.2	0.222 1.00 1.22 1.33	0.0051 1.00 0.30 0.23	150 150 90 120	0.8 150 27 28	155
1.1	0.2 0.9 1.1 1.2	0.182 0.82 1.00 1.09	0.0034 0.20 1.00 0.53	150 150 90 120	0.5 30 90 64	114
1.2	0.2 0.9 1.1 1.2	0.167 0.75 0.92 1.00	0.0028 0.125 0.48 1.00	150 150 90 120	0.4 19 43 120	129

is calculated for each transmission. Here E_m is the measured or calculated field strength and E_s is a safe field strength for the frequency concerned and for the arrangement of EED being considered. Values of E_s for standard commercial EED* are given in Fig.s 9, 10 and 11 of the Guide; for tuned loops E_s = 2V/m for standard EED at all frequencies. For non-standard EED, E_s should be multiplied by one of the factors given in Clause 9.4 of Reference 2.

The current induced in the EED is proportional to E_m; if $E_m = E_s$ the induced current is equal to the "no-fire" current*. Thus if ρ exceeds unity with a single transmission a hazard is indicated.

An overall assessment for multiple transmissions is obtained by adding all of the values of ρ. Since the induced currents are proportional to E_m this procedure is equivalent to adding the squares of the individual currents. If the sum exceeds unity a hazard is indicated. However if Fig. 12 of Reference 2 shows that a given loop could be resonant at two or more of the frequencies there may not be a hazard and ρ should therefore be re-calculated as follows.

The loop should be assumed to be tuned in turn to each of the frequencies at which tuning is possible. The effective current is calculated for each tuning condition, as in the example in Section 3 of this report, and the largest value selected; let this current be denoted by I_o. Then for the group of frequencies at which the loop can be tuned:-

$$\rho = \left(\frac{I_o}{I_{nf}}\right)^2 \tag{8}$$

where I_{nf} is the no-fire current for the type of EED being considered. This value of ρ is then added to any values of ρ calculated by Equation (7) for frequencies at which the loop does not tune. If the sum still exceeds 1.0 a potential hazard is indicated, but if it is now less than unity then EED can be safely used.

* EED are available with a range of sensitivities. A "standard-sensitivity commercial EED" is one whose probability of ignition (measured by statistical analysis of random sampling data) is not greater than 0.01% when a current of 300 mA is applied; this current is known as the "no-fire" current.

5. Conclusions

A loop containing EED can only be tuned to one frequency at a time. If it is capable of being tuned to more than one transmission frequency, a safety assessment based on the resonant currents, with no allowance for detuning, might indicate a hazard where none exists. However the currents at the off-tune frequencies cannot be disregarded even though they are smaller than the resonant values.

The procedure described here should be used for safety assessments if a loop is tunable to more than one transmission, when exposed to several transmissions simultaneously. Its use is recommended in the British Standard Guide to the prevention of inadvertent initiation of electro-explosive devices by radio-frequency radiation.

6. References

1. BISHOP, A.E. *and* KNIGHT, P. The safe use of electro-explosive devices in electromagnetic fields, 1983. To be published.

2. British Standard Guide to prevention of inadvertent initiation of electro-explosive devices by radio-frequency radiation. British Standards Institution. In preparation (1983).

3. British Standard Guide to the prevention of inadvertent ignition of explosive atmospheres by radio-frequency radiation. British Standards Institution. In preparation (1983).

4. KNIGHT, P. Radio-frequency ignition hazards: the power available from non-resonant structures. BBC Research Department Report 1982/3.

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